## Title
Linear and Nonlinear Response of a Nb/Al{sub 2}O{sub 3}/Nb Tunnel Junction to Picosecond Electrical Pulses



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# *Linear and Nonlinear Response of a $Nb/Al_2O_3/Nb$ Tunnel Junction to Picosecond Electrical Pulses*

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## Abstract

We have made the first time resolved measurement of the quasiparticle current in a superconducting tunnel junction induced by picosecond electrical pulses propagating in free space.

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**Summary**

We have used picosecond electrical pulses to measure the broadband quasiparticle response of a Nb trilayer superconductor-insulator-superconductor (SIS) junction in both the linear and nonlinear regimes. Electrical pulses are especially well suited to the nonlinear regime since large instantaneous voltages can be applied while the average power is kept low.

The broadband response of the SIS device is inferred from the dc current induced by interfering two electrical pulses at the junction, as a function of the time delay between them. Figure 1 is a schematic diagram of the interferometer [1]. The electrical pulses were generated by illuminating a silicon photoconducting switch at the feed of a 300 μm dipole antenna. A Ti-Sapphire laser producing 100 fs pulses excites the photoconductive switch, generating an electrical pulse with duration ≈ 10 ps, centered at 180 GHz. The electrical

pulses from two separate antennas are collimated by lenses and parabolic mirrors and then combined with a mylar beamsplitter. A final parabola directs the pulses onto the polypropylene window of a 4.2K cryostat which houses the junction. The radiation is then coupled to the SIS junction via a quartz hyperhemisphere and a log-periodic planar antenna.

The SIS junction can be modeled as a superposition of voltage tunable two level systems [2]. The BCS theory [3] predicts strong absorption for $hf_0 \geq 2\Delta - eV_{bias}$, where $V_{bias}$ is the dc voltage across the junction. In response to a voltage pulse, the current is expected to oscillate near the frequency $f_0$ and to decay with a lifetime related to the broadening of the dc I-V curve. For our SIS junction, $2\Delta = 2.75$ meV and the measured width of the threshold in the dc I-V curve corresponds to a decay time of 10 ps.

The signal generated by two electrical pulses incident on the junction as a function of the time delay between them is shown in Figure 2a. $V_{bias}$ was varied from 2.6 mV to 2.0 mV, tuning $f_0$ from 36 GHz to 180 GHz. The shift in relative spectral weight from low to high frequencies is seen clearly in Fourier transforms of these data shown in Figure 2b.

Figure 3 shows the result of a measurement similar to Fig. 2a, except that $V_{bias} = 1.0$ mV, corresponding to $f_0 = 420$ GHz. At this bias, the linear response is expected to be small since the 420 GHz component of the electrical pulse is negligible. The observed response shows direct evidence for a nonlinear mechanism, i.e. two photon absorption. For example the signal scales as the electric field amplitude to the fourth power. In addition the "interference" pattern is rectified in that the current has a large dc component.

In conclusion, we have applied the technique of picosecond electrical pulse generation to study the time-domain response of a SIS tunnel junction in the linear and nonlinear regimes. The successful measurement of two-photon absorption in an SIS junction demonstrates the application of picosecond electrical pulses to time-resolved non-linear spectroscopy.

**References:**

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**Figure Captions:**

**Fig. 1:** Schematic layout of the picosecond electrical pulse interferometer

**Fig. 2:** (a) Quasiparticle current generated by two electrical pulses versus time delay between them, for several values of $V_{bias}$. (b) Amplitude of the Fourier transforms of the data in (a).

**Fig. 3:** Two photon cross-correlation showing rectification with the SIS junction biased at 1.0 mV.

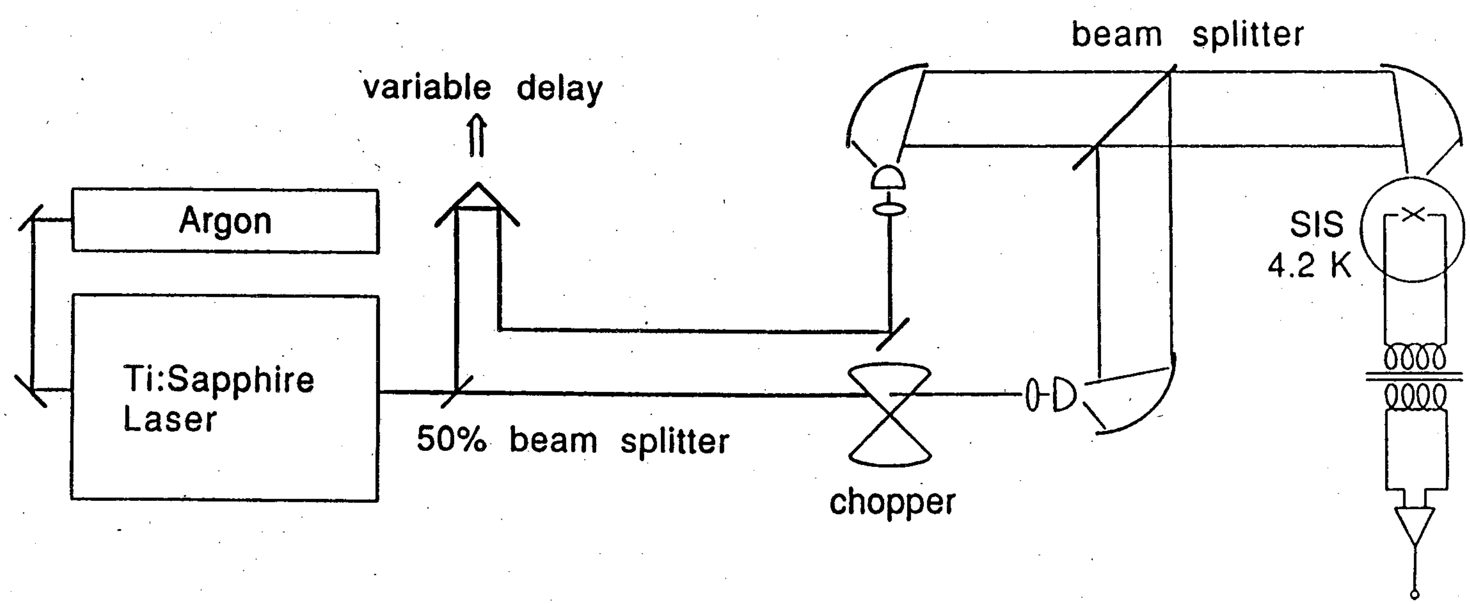
beam splitter
variable delay
Argon
SIS
4.2 K
Ti:Sapphire
Laser
50% beam splitter
chopper

Figure 1

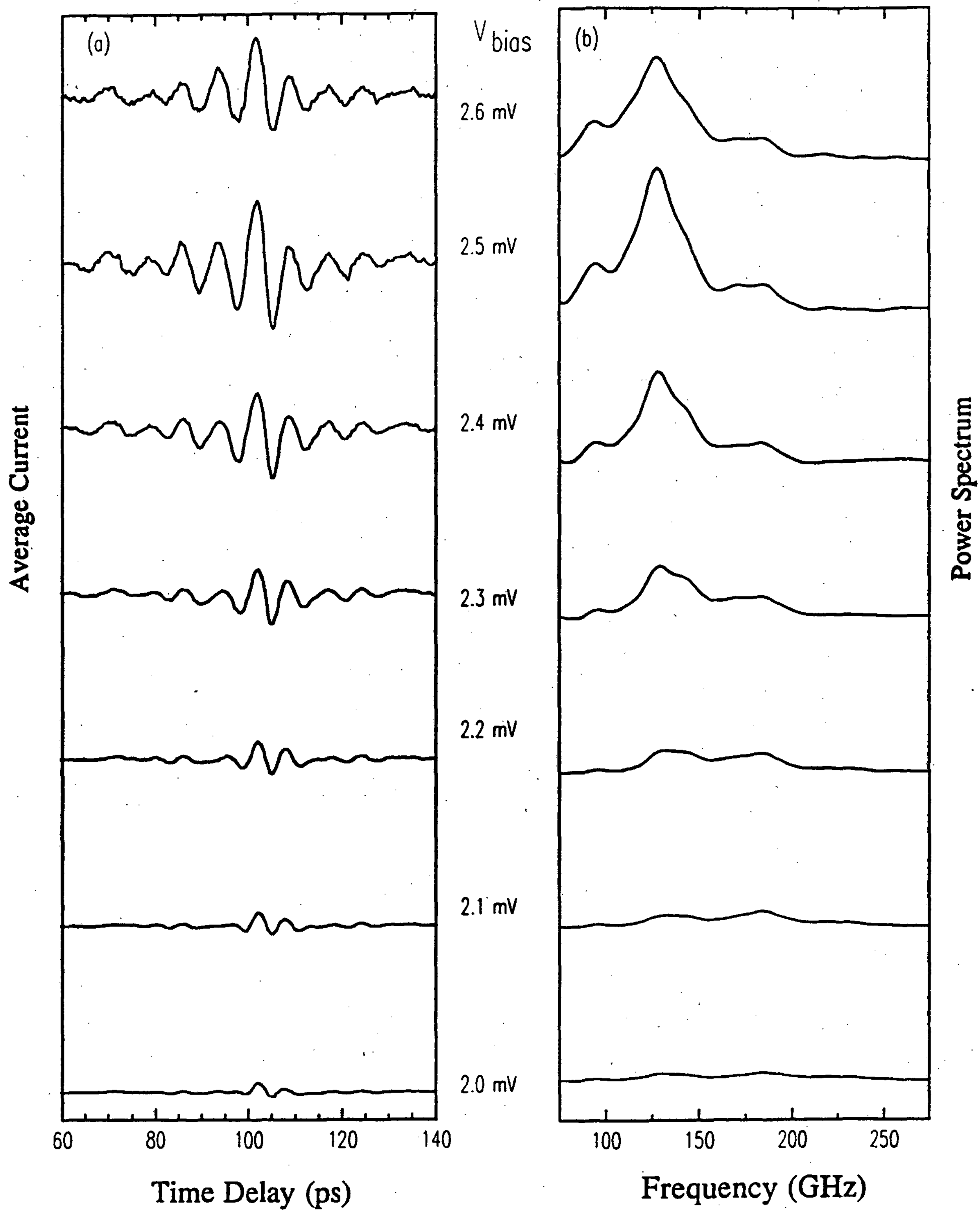
(a)
V bias
2.6 mV
2.5 mV
2.4 mV
2.3 mV
2.2 mV
2.1 mV
2.0 mV
Average Current
60
80
100
120
140
Time Delay (ps)
(b)
Power Spectrum
100
150
200
250
Frequency (GHz)

Figure 2

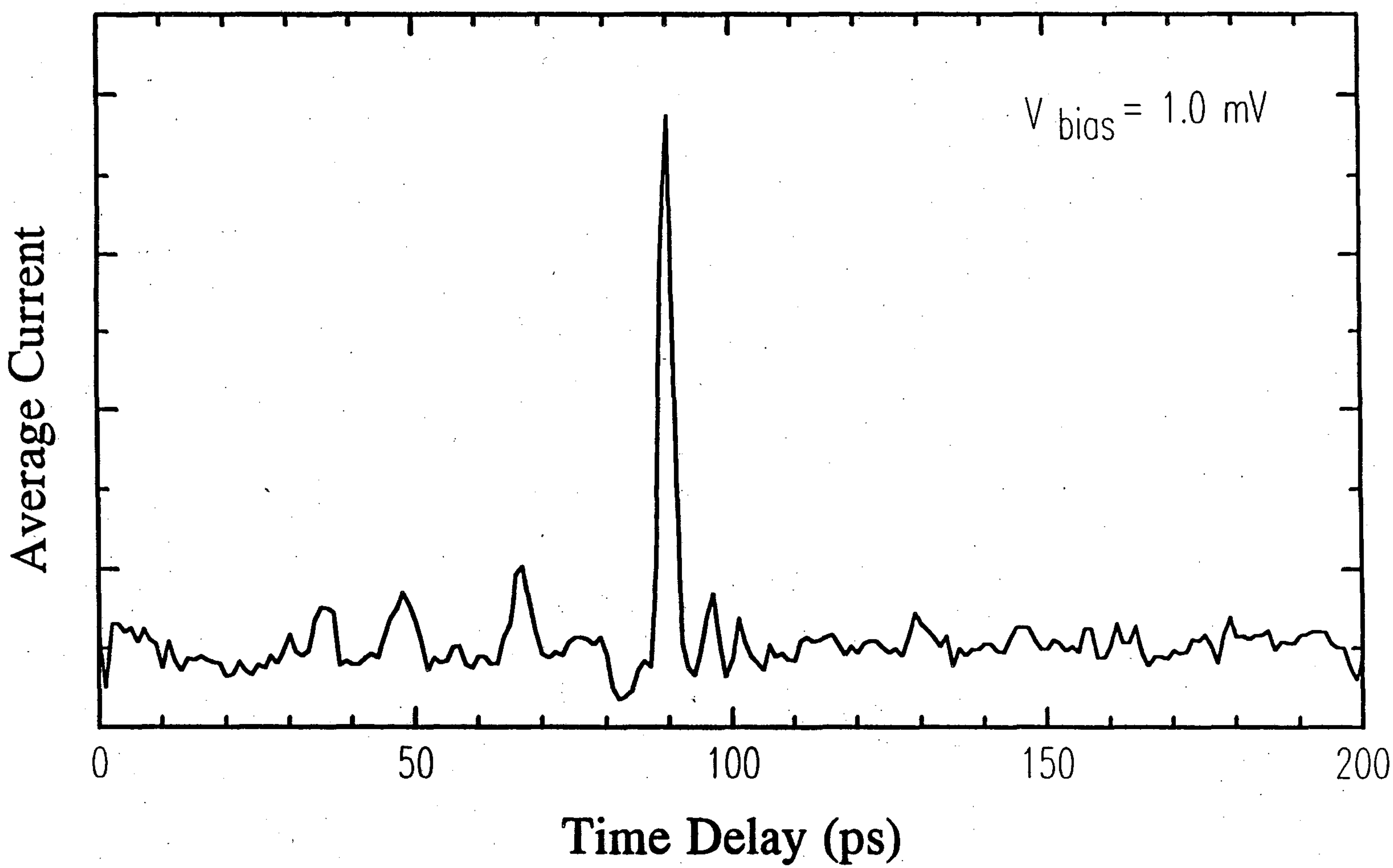


Figure 3

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